

Chapter 8

RADIOLOGICAL ASSESSMENT OF RECYCLING ALUMINUM

Detailed descriptions of the practices of recycling aluminum are presented in Appendix B. The present chapter recapitulates those aspects of these practices which are relevant to the assessment of the radiation exposures of individuals. The exposure pathways are the same as those discussed in Section 5.3. Differences in exposure parameters applicable to the aluminum assessment are described in the following sections.

Figure 8-1 presents a simplified diagram depicting the mass flow during aluminum recycling. As shown in the figure, the aluminum scrap from normal commercial sources as well as from a nuclear facility is sent to a reverberatory furnace to be smelted. The furnace produces aluminum alloys, as well as the smelting by-products: dross and offgas. The dross, primarily consisting of metallic oxides and halide salts, is analogous to the slag produced during the melt-refining of carbon steel, while the offgas contains volatile products and aerosols emitted by the furnace.

8.1 DISTRIBUTION OF CONTAMINANTS

8.1.1 Material Balance

The following mass fractions were adopted for the present analysis¹ (see Section B.6.1):

Furnace Charge:

- Aluminum scrap 0.735
- Heel from previous melt . . 0.25
- Silicon 0.015

Output:

- Aluminum casting alloy . . 0.943 (0.25 left in furnace)
- Baghouse dust 0.00225 (0.0015 metal)
- Dross 0.112 (0.056 Al₂O₃, 0.045 halide salts, 0.0112 Al metal)

¹ Most of these values are lower than those cited in Section B.6.1. The latter value refers to the scrap + silicon charged to the furnace, while the present values refer to the total metal in the furnace, which includes the heel from the previous melt.

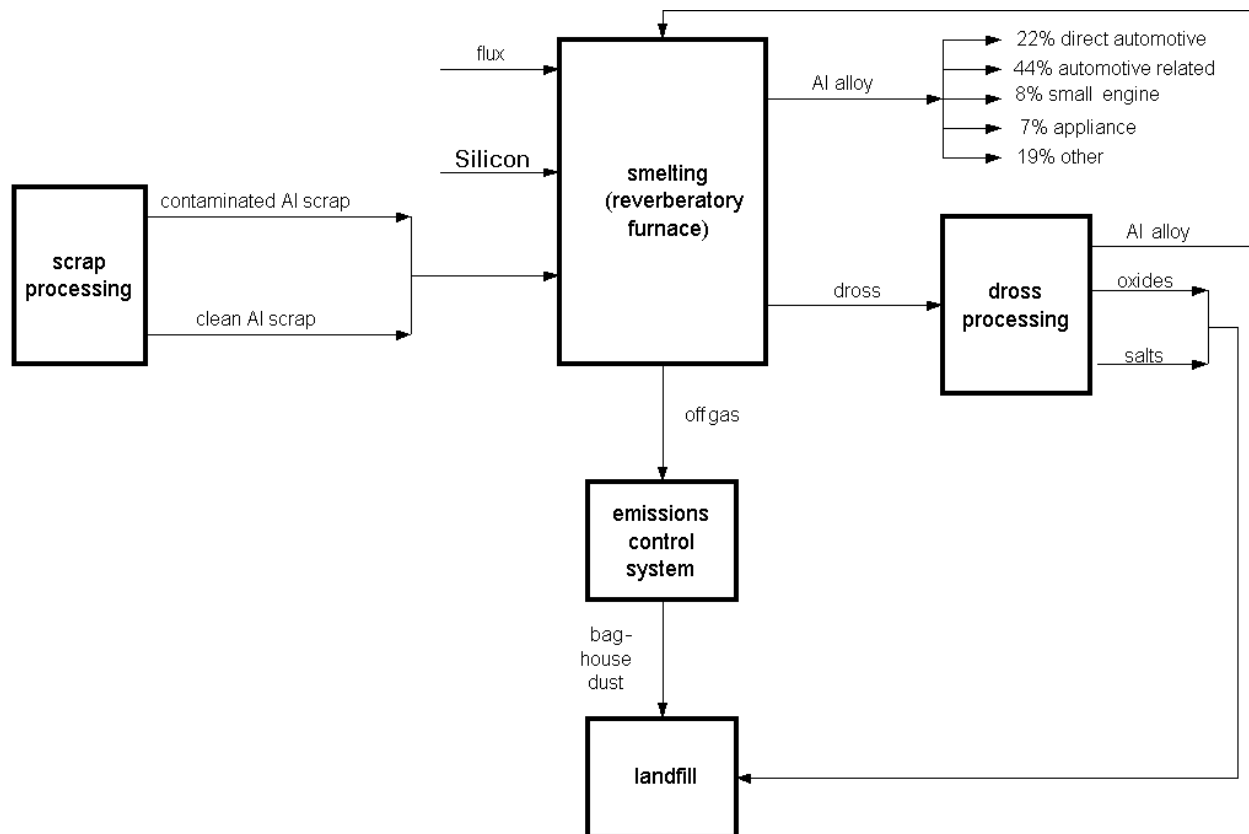


Figure 8-1. Simplified Material Flow for Secondary Aluminum Smelter

The sum of the output fractions is greater than 1 due to the addition of flux to the furnace charge, as well as oxidation of the aluminum in the dross.

8.1.2 Contaminant Partitioning

Table 8-1 lists the partition ratios of the various elements, taken from Table B-13. The concentration factors are calculated according to the methodology presented in Section 6.2, using the mass fractions in Section 8.1.1. The calculation of the concentration factor in the furnace charge assumes that the scrap consists of 98.5% old scrap, and 1.5% scrap recovered from the dross produced in previous melts. This recovered scrap would have the same specific activities as the finished metal.

Table 8-1. Partition Ratios (PR) and Concentration Factors (CF) in Aluminum Smelting

Element	Furnace Charge CF ^a	Metal		Dross		Release Fraction ^b
		PR (%)	CF	PR (%)	CF	
Ac	0.85	1 - 50	0.44	50 - 99	7.07	8.88e-05
Ag	0.99	100	1.03		0	2.05e-04
Am	0.85	1 - 50	0.44	50 - 99	7.07	8.88e-05
C	0.75	1 - 10	0.08	90 - 99	7.07	1.56e-05
Ce	0.85	1 - 50	0.44	50 - 99	7.07	8.88e-05
Cm	0.85	1 - 50	0.44	50 - 99	7.07	8.88e-05
Co	0.98	90 - 99	1.01	1 - 10	0.95	2.03e-04
Cs	0.72	0	0.00	100	7.11	0.00e+00
Eu	0.85	1 - 50	0.44	50 - 99	7.07	8.88e-05
Fe	0.98	90 - 99	1.01	1 - 10	0.95	2.03e-04
I	0.72	0	0.00	50 - 100	7.11	0.0 - 0.5
Mn	0.98	90 - 99	1.01	1 - 10	0.95	2.03e-04
Mo	0.99	100	1.03		0.00	2.05e-04
Nb	0.98	90 - 99	1.01	1 - 10	0.95	2.03e-04
Ni	0.98	90 - 99	1.01	1 - 10	0.95	2.03e-04
Np	0.85	1 - 50	0.44	50 - 99	7.07	8.88e-05
Pa	0.98	1 - 99	1.01	99 - 1	7.07	2.03e-04
Pb	0.99	100	1.03		0	2.05e-04
Pm	0.85	1 - 50	0.44	50 - 99	7.07	8.88e-05
Pu	0.85	1 - 50	0.44	50 - 99	7.07	8.88e-05
Ra	0.85	1 - 50	0.44	50 - 99	7.07	8.88e-05
Ru	0.99	100	1.03		0	2.05e-04
Sb	0.99	100	1.03		0	2.05e-04
Sr	0.75	1 - 10	0.08	90 - 99	7.07	1.56e-05
Tc	0.99	100	1.03		0.00	2.05e-04
Th	0.85	1 - 50	0.44	50 - 99	7.07	8.88e-05
U	0.85	1 - 50	0.44	50 - 99	7.07	8.88e-05
Zn	0.98	90 - 99	1.01	1 - 10	0.95	2.03e-04

^a Refers to the scrap aluminum (98.5% old scrap and 1.5% scrap recovered from dross) + silicon charged to the furnace

^b Atmospheric releases, assuming compliance with the draft EPA emission standard of 0.4 lb per ton of furnace charge

8.2 LIST OF OPERATIONS AND EXPOSURE SCENARIOS

Table 8-2 lists the operations and exposure parameters employed in the radiological assessment. The descriptive title of each individual exposure scenario—used to assess the exposure of a given individual—is italicized. (Sub-scenarios listed beneath the individual scenario refer to different activities performed by the same individual.) These operations are described in the following sections. The scenarios were selected from a larger list of possible scenarios discussed in Appendix B. The aim of the selection was to ensure that the reasonable maximum exposures from each radionuclide would be evaluated. Scenarios were omitted if the radiation sources, exposure pathways, and exposure durations were such that the radiation exposures would be bounded by the scenarios already selected. Further details are found in Appendix B.

8.2.1 Dilution

Scrap Transport

It is assumed that aluminum scrap from a nuclear facility would be transported to a smelter in a dedicated truck. Therefore, the dilution factor for this operation is equal to 1.

Smelter Operations

Unlike carbon steel, movement of aluminum scrap is not geographically constrained by haulage costs. The reference smelter for the aluminum recycling assessment is based on the Wabash Alloys facility in Dickson, Tenn., which has an annual capacity of about 75,000 tons (68,000 metric tons [t]). As discussed in Section B.1.1, the largest anticipated release of aluminum scrap from a single facility in any one year is the 2,527 t of aluminum from Paducah available each year from 2016 to 2022. Assuming all of this scrap is processed at the reference smelter, the dilution factor is 0.037. The same factor is applied to the industrial use scenario.

Dross Disposal

The dilution factor for the dross being transported for disposal is the same as for the smelter operations. In the realistic landfill burial scenario described in Appendix L, the dross from the reference smelter is commingled with dross from other smelters, resulting in an overall dilution factor of 1.3×10^{-3} . The derivation of this factor is discussed in Appendix L.

Table 8-2
Exposure Scenarios and Parameters for Radiological Assessments of Aluminum Recycling

Description	Dilution factor	Exposure Pathways							
		External Exposure			Internal				
		Time (hr/y)	Distance	Medium	Time (hr/y)	Medium	Dust load (mg/m ³)	RF ^a	
SCRAP TRANSPORT: <i>Truck driver</i>	1.	1000	8 ft	scrap	N/A				
SECONDARY SMELTER	0.037								
Scrap Operations									
<i>Scrap handler</i>		875	b	scrap	1750	scrap	0.85	0.6	
		875	10 ft						
<i>Shredder operator</i>		1750	3 -10 ft ^d		1750		10	0.5	
Furnace Operations									
<i>Furnace operator:</i>					1750	dust ^c	0.57	0.6	
near furnace		1500	6 ft	scrap					
misc. duties		250	25 ft						
<i>Airborne effluent emissions</i>		N/A							
Handling Ingots									
<i>Skimmer and stacker</i>					1750	dust	0.85	0.6	
skim ingot		250	1.5 ft	metal					
			40 in	dross					
stack ingots		750	15 in	metal					
			1.5 - 6 ft	metal					
operate fork lift		750	3 ft	metal					
Dross Disposal									
<i>Dross transport: truck driver</i>			1000	8 ft	dross	N/A			
<i>Dross buried in landfill</i>	0.0013	N/A							
INDUSTRIAL USE OF MILL PRODUCTS									
<i>Aluminum fabricator</i>	0.037	1300	1 ft	metal	875	metal	7.66	1.0	
END USERS	0.5								
<i>Taxi driver: engine block</i>		3300	0.8 m						
<i>Truck driver: fuel tank</i>		3000	2.5 ft	metal	N/A				
<i>Cooking in aluminum pan</i>		263	2 ft		N/A ^e	metal	N/A		

^a Respirable fraction

^b Exposure assessment uses FGR 12 dose coefficients—see discussion in Section 6.3.1

^c Dust = baghouse dust

^d Range of distances—see discussion in Section 6.3.1

^e Exposure from ingestion of contaminated food

End Users

As was the case with carbon steel scrap, it is highly unlikely that all of the aluminum scrap in a single furnace heat will be from a nuclear facility. In addition to dilution caused by charging the furnaces with different batches of scrap, about 25% of the charge consists of molten aluminum from the previous heat. Thus, a dilution factor of 0.5—the value used for finished products made of carbon steel—is reasonably conservative for the aluminum assessment.

8.2.2 Scrap Transport

The scrap transport worker is a truck driver who spends eight hours per day in the cab of a truck, carrying 20-t loads of scrap metal to the scrap processor and returning with an empty truck (or carrying other cargo).² His only exposure would be to external radiation from the load of contaminated scrap.

The MicroShield computer program was used to calculate normalized dose rates to the driver from external exposure. The scrap was assumed to fill a trailer that was 48 ft long, 8 ft wide and 9½ ft high—typical dimensions for a large cargo trailer. The driver was assumed to sit 8 ft in front of the load, the doses being calculated for the posteroanterior (PA) exposure geometry, which corresponds to the driver having his back to the load. The attenuation of the walls of the trailer and cab and of the driver's seat were neglected, leading to a slightly conservative assessment.

8.2.3 Secondary Smelter Operations

Aluminum recycling operations at a secondary smelter may be divided into four categories: (1) scrap handling and processing, (2) furnace operations, (3) handling and processing of ingots, and (4) disposal of dross. Two scrap workers—a scrap handler and a shredder operator—were included in the exposure assessments, as were a furnace operator, a worker who performs different tasks involved in the processing and handling of ingots, and a truck driver who transports the dross for disposal. All these workers would be exposed to direct radiation from the residual radioactivity of the metal. All but the driver would also inhale potentially contaminated dust in the ambient air and ingest deposited particulate matter.

² According to Section B.6.2, transporting the 2,527 t/a of scrap from generated at Paducah to Dickson, Tenn. would require 126 trips. The analysis of this scenario, however, considers the possibility that the scrap may be smelted at a more distant facility, which would require the driver of a dedicated truck to spend an entire year transporting this material.

Scrap Handler

The scrap handler moves scrap from the stockpiles to the shredder or the furnace using a front-end loader with a 5-yd³ bucket—the bucket would be loaded one-half of the time. The sources of his external exposure would be the load in the bucket and the scrap piles.

The contents of the bucket were modeled as a 3-m-long cylinder, 1.3 m in diameter, with a bulk density of 1.08 g/cm³. Because of the size and distribution of the scrap piles, this source was modeled as one-half of an infinite plane, using the dose coefficients for exposure to soil contaminated to an infinite depth, as listed in Federal Guidance Report (FGR) No. 12 (Eckerman and Ryman 1993), but dividing each value by 2.

The dust loading is the average of the eight measured values listed in Table B-7. The respirable fraction—the mass fraction with aerodynamic diameters $\leq 10 \mu\text{m}$ —was taken from the size distribution of particles in uncontrolled particulate emissions from refining operations in secondary aluminum smelters employing reverberatory furnaces, as listed in U.S. EPA 1995.

Shredder Operator

The shredder operator stands near the scrap conveyor, which transports a stream of scrap, 3 ft wide by ½ ft deep with a bulk density of 50%. A dust loading of 12.17 mg/m³ had been measured at a scrap conveyer (see Section B.4.3). The analysis assumes that the operator's non-radiological inhalation exposure would comply with recommendations of the American Council of Governmental and Industrial Hygienists (ACGIH 1996),³ so that the total dust loading would not exceed a time-weighted average (TWA) of 10 mg/m³ and the respirable dust concentration would not exceed 5 mg/m³.

Furnace Operator

The furnace operator spends most of his time tending the furnace at an average distance of 6 ft from the charge and about one hour per day performing other duties which place him 25 ft from the furnace.

³ The ACGIH total dust loading is lower than the OSHA PEL of 15 mg/m³ for nuisance dust; however, the TWA concentration of respirable dust is the same as the OSHA PEL.

Skimmer and Stacker

During the pouring of the melt from the furnace, a worker is assigned to skimming dross from the ingot surface. Because this is a part-time activity, the same person is assumed to work on the crew stacking ingots onto pallets. These crew members divide their time between manually stacking the ingots and transporting the pallets with a forklift.

During the dross skimming operation, the worker's external exposure is from an ingot which measures $4 \times 4 \times 22.5$ inches and weighs 35 lb, and from a waste container 40 inches away that, on average, is half-full of dross. The dross is modeled as a rectangular solid measuring $20 \times 78 \times 41$ in. During stacking, he is exposed to one ingot carried close to his body (assumed to be 15 inches from the center of the body) and to the pile of 27 ingots—one-half of a fully stacked pallet—at a distance that varies between 1.5 and 6 ft. While operating the fork lift, he is exposed to a fully stacked pallet of 54 ingots.

Dross Transport

The dross transport worker is a truck driver who spends eight hours per day in the cab of a truck, carrying 20-ton loads of dross for processing or disposal and returning with an empty truck (or carrying other cargo). His only exposure would be to external radiation from the load of contaminated dross. This assessment used the same exposure geometry as that of the carbon steel scrap truck, which is described in Section H.1.1.

8.2.4 Industrial Uses of Mill Products: Aluminum Fabrication

The aluminum fabrication worker performs gas metal arc welding on a wrought aluminum base. His exposure pathways consist of external exposure to the base metal and the inhalation of fumes from welding. When not wearing his helmet, he would be exposed to the inadvertent ingestion of deposited particulates. The source of external exposure is modeled as a 4.7-ft-square, $\frac{1}{2}$ -inch-thick sheet of aluminum. The exposure rates for all γ -emitting nuclides except Mo-93 were calculated by means of the MicroShield computer program, as described in Section 6.3.1. The exposure rate from Mo-93 was calculated in a manner analogous to that used to calculate the exposure rate from the hull plate, also described in Section 6.3.1. The fume concentration inside the helmet was assumed to be the highest of the values listed in Table B-16.

8.2.5 Use of Finished Products

As is the case with steel, aluminum is also used to make a virtually endless variety of finished products. The analysis considers three users of finished products: the driver of a truck with an aluminum fuel tank, the driver of a taxi with an aluminum engine block, and a person who cooks in an aluminum utensil.

Taxi Driver

The maximally exposed taxi driver is assumed to be an owner/operator who drives a taxi with an aluminum engine. According to the information presented in Section B.6.2, the largest aluminum engine block weighs about 80 lb (36 kg). MicroShield was used to calculate normalized external dose rates to this driver. The dimensions of the block, as well as other exposure parameters, are assumed to be the same as for the corresponding scenario in the carbon steel analysis (see Sections H.11.1 and H.13.2). The dose rates from Th-232 and Ra-228+D were adjusted to account for the ingrowth of progeny during the useful life of this product, as discussed in Section 8.4.4.

Driver of Truck with Aluminum Fuel Tank

The only exposure pathway of the driver of a truck with an aluminum fuel tank is to direct radiation from the tank, which is located under the cab of the truck. The tank is made of ¼-inch thick aluminum and is 1 ft high and 3.7 ft square, with a capacity of 100 gal. On average, the tank would be half-full of fuel. The driver sits 2½ feet above the tank, and is shielded by an additional ¼ inch of aluminum in the floor of the cab.

Cooking Utensil

A consumer cooking food in an aluminum frying pan may be exposed to direct radiation from the metal in addition to eating food which may be contaminated with residual radioactivity that has leached from the pan. Blumenthal (1990) wrote that “. . . a person using uncoated aluminum pans for all cooking and food storage every day would take in an estimated 3.5 milligrams of aluminum daily.” This intake rate serves as a conservative upper bound for the leaching of aluminum from the residually contaminated frying pan. The external exposures calculated for the cast iron pan serve as a conservative upper bound for the present analysis. This is because the greater mass of the iron pan would contain a higher total activity of a given radionuclide, which more than compensates for the slightly higher self-absorption of iron vs. aluminum. Since the external exposure from this small object, which is used for a relatively few hours per year, is

not a significant dose pathway, the use of the more conservative results has little impact on the analysis.

8.2.6 Off-Site Individuals Exposed to Smelter By-Products

Additional exposure assessments were performed on two off-site individuals. One is a nearby resident who is exposed to the unfiltered airborne effluents from the smelter. The other resides near an industrial landfill used to dispose of the dross.

Impact of Fugitive Airborne Emissions on Nearby Residents

The assessment of nearby residents exposed to fugitive airborne emissions of C-14 and I-129 from the furnace utilized the results of the analysis of this pathway described in Chapter 6. The analysis of other radionuclides was based on a previous assessment of the recycling of carbon steel scrap (SCA 1995), which explicitly evaluated this pathway for 24 of the nuclides in the present analysis. The impacts were adjusted for the annual releases of each nuclide, as follows:

$$D_{ia} = \frac{D'_{ia} Q_i}{Q'_i}$$

D_{ia} = 50-year dose commitment from airborne effluent releases of nuclide i

D'_{ia} = dose commitment from airborne effluent releases of nuclide i from previous analysis

Q_i = activity of nuclide i released from smelter in one year
 $= f_{ri} M_c$

f_{ri} = release fraction of nuclide i (see Table 8-1)

M_c = mass of cleared aluminum scrap processed in one year
 $= 2.527 \text{ Gg (2,527 t)}$

Q'_i = released activity of nuclide i in previous analysis

The doses from C-14 and I-129 were adjusted for the dose conversion factors from ICRP Publication 68 (ICRP 1994), as discussed in Section 6.4.3. The assessment of impacts from the airborne emissions scenario is presented in Table 8-3.

Table 8-3. Normalized Impacts from One Year of Exposure to Fugitive Airborne Emissions

Nuclide	Reference Analysis ^a			Aluminum			
	μCi/y	Dose (mrem/y)	Risk	Release Fraction ^b	μCi/y	Dose ^c	Risk ^d
C-14	11,000	4.86e-04	2.13e-10	1.56e-05	0.0394	1.8e-09	1.1e-15
Mn-54	13.1	7.46e-05	4.30e-11	2.03e-04	0.513	2.9e-06	1.7e-12
Co-60	13.1	8.80e-04	4.80e-10	2.03e-04	0.513	3.4e-05	1.9e-11
Ni-59	—	—	—	2.03e-04	0.513	5.9e-09	1.3e-15
Ni-63	13.1	4.16e-07	1.00e-13	2.03e-04	0.513	1.6e-08	3.9e-15
Sr-90+D	13.1	9.01e-05	9.20e-12	1.56e-05	0.039	2.7e-07	2.8e-14
Tc-99	13.1	8.41e-07	5.00e-13	2.05e-04	0.518	3.3e-08	2.0e-14
Ru-106+D	13.1	3.77e-05	2.10e-11	2.05e-04	0.518	1.5e-06	8.3e-13
I-129	15,000	4.48e-01	2.52e-07	5.00e-01	1,264	5.6e-02	2.5e-08
Cs-134	1,310	3.56e-02	2.07e-08	0.00e+00	0.000	0.0e+00	0.0e+00
Cs-137+D	1,310	4.08e-02	2.25e-08	0.00e+00	0.000	0.0e+00	0.0e+00
Pb-210+D	1,310	1.60e-01	2.60e-08	2.05e-04	0.518	6.3e-05	1.0e-11
Ra-226+D	13.1	4.86e-03	3.21e-09	8.88e-05	0.224	8.3e-05	5.5e-11
Ra-228+D	13.1	7.67e-04	3.00e-10	8.88e-05	0.224	1.3e-05	5.1e-12
Ac-227+D	13.1	4.01e-01	4.85e-09	8.88e-05	0.224	6.9e-03	8.3e-11
Th-228+D	13.1	1.44e+00	5.41e-07	8.88e-05	0.224	2.5e-02	9.3e-09
Th-229+D	13.1	1.29e-01	5.08e-09	8.88e-05	0.224	2.2e-03	8.7e-11
Th-230	13.1	1.94e-02	1.03e-09	8.88e-05	0.224	3.3e-04	1.8e-11
Th-232	13.1	9.77e-02	1.15e-09	8.88e-05	0.224	1.7e-03	2.0e-11
Pa-231	13.1	7.65e-02	1.46e-09	2.03e-04	0.513	3.0e-03	5.7e-11
U-234	13.1	7.87e-03	8.40e-10	8.88e-05	0.224	1.3e-04	1.4e-11
U-235+D	13.1	7.39e-03	8.10e-10	8.88e-05	0.224	1.3e-04	1.4e-11
U-238+D	13.1	7.04e-03	7.50e-10	8.88e-05	0.224	1.2e-04	1.3e-11
Np-237+D	13.1	3.23e-02	2.08e-09	8.88e-05	0.224	5.5e-04	3.6e-11
Pu-238	—	—	—	8.88e-05	0.224	4.0e-04	2.8e-11
Pu-239/240	13.1	2.56e-02	1.66e-09	8.88e-05	0.224	4.4e-04	2.8e-11
Pu-241+D	13.1	4.93e-04	1.70e-11	8.88e-05	0.224	8.4e-06	2.9e-13
Pu-242	—	—	—	8.88e-05	0.224	4.2e-04	2.7e-11
Am-241	13.1	2.65e-02	2.31e-09	8.88e-05	0.224	4.5e-04	4.0e-11

^a C-14 and I-129 results from carbon steel analysis in present report; results for other nuclides from SCA 1995

^b Table 8-1

^c mrem EDE per pCi/g in scrap

^d Lifetime risk of cancer per pCi/g in scrap

Fourteen of the nuclides considered in the present analysis were not included in either of the analyses cited above. In some of the omitted cases, however, a different isotope of the same element can serve as a surrogate for the missing radionuclide. The impacts of Ni-59 can be estimated from the results for Ni-63. Both isotopes emit β -rays or Auger electrons, and neither emits penetrating photons. The report of the earlier analysis (SCA 1995) shows that the principal impact of atmospheric emissions of Ni-63 was via the inhalation pathway. The Ni-59 dose was therefore estimated from the ratio of the dose conversion factors (DCFs) for inhalation of the two isotopes, as listed in Federal Guidance Report No. 11 (Eckerman et al. 1988), the source of the DCFs in the earlier analysis. The risk was estimated from the ratio of the corresponding slope factors (U.S. EPA 1994). Pu-238, Pu-239, Pu-240 and Pu-242 are all α -emitters with no short-lived progenies. Pu-239 and Pu-240 have almost identical DCFs for both the ingestion and inhalation pathways—they are therefore listed on the same line in the table. The doses and risks from Pu-238 and Pu-242 via this pathway were estimated on the basis of the corresponding values for Pu-239 by a method analogous to the one used for Ni-59.

Disposal of Dross in an Industrial Landfill

Dross is commonly buried in a RCRA Subtitle D solid waste landfill. It is possible that a nearby resident would be exposed by drinking groundwater contaminated by leachate from the landfill. This could only occur after the closure of the landfill and loss of institutional control, after which the cap is assumed to degrade and fail. The details of the analysis are presented in Appendix L.

8.3 RESULTS

The results of the aluminum recycling assessment are shown in Table 8-4. Several observations can be made about these data:

- The normalized doses from all but one of the radionuclides (C-14) from the recycling of aluminum are lower than from the recycling of carbon steel.
- Workers are the RME individuals for all nuclides except C-14, I-129, and Np-237.
- Three scenarios account for the reasonably maximum doses from all 44 nuclides and nuclide combinations. These are discussed in the following sections.

Table 8-4. Maximum Exposure Scenarios and
Normalized Impacts on the RME Individual from One Year of Exposure

Nuclide	Maximum Scenario	Dose		Lifetime Risk of Cancer ^a	
		mrem EDE per pCi/g	μSv per Bq/g	per pCi/g	per Bq/g
C-14	Dross in landfill	3.4e-04	9.2e-02	1.6e-10	4.4e-09
Mn-54	Scrap truck driver	6.7e-02	1.8e+01	5.1e-08	1.4e-06
Fe-55	Scrap shredder	2.9e-06	7.8e-04	6.7e-13	1.8e-11
Co-60	Scrap truck driver	2.0e-01	5.4e+01	1.5e-07	4.1e-06
Ni-59	Scrap shredder	6.2e-07	1.7e-04	4.0e-13	1.1e-11
Ni-63	Scrap shredder	1.5e-06	4.0e-04	1.1e-12	3.0e-11
Zn-65	Scrap truck driver	4.6e-02	1.3e+01	3.5e-08	9.5e-07
Sr-90+D	Scrap shredder	3.7e-04	9.9e-02	9.9e-11	2.7e-09
Nb-94	Scrap truck driver	1.3e-01	3.4e+01	9.6e-08	2.6e-06
Mo-93	Scrap shredder	2.6e-05	7.1e-03	2.0e-11	5.4e-10
Tc-99	Scrap shredder	9.3e-06	2.5e-03	2.9e-12	7.9e-11
Ru-106+D	Scrap truck driver	1.7e-02	4.5e+00	1.3e-08	3.4e-07
Ag-110m+D	Scrap truck driver	2.2e-01	5.9e+01	1.7e-07	4.5e-06
Sb-125+D	Scrap truck driver	3.3e-02	9.0e+00	2.5e-08	6.8e-07
I-129	Dross in landfill	6.5e-02	1.7e+01	2.9e-08	7.9e-07
Cs-134	Scrap truck driver	1.3e-01	3.4e+01	9.5e-08	2.6e-06
Cs-137+D	Scrap truck driver	4.5e-02	1.2e+01	3.4e-08	9.3e-07
Ce-144+D	Scrap truck driver	3.5e-03	9.5e-01	2.7e-09	7.2e-08
Pm-147	Scrap shredder	8.0e-06	2.2e-03	4.7e-12	1.3e-10
Eu-152	Scrap truck driver	8.9e-02	2.4e+01	6.7e-08	1.8e-06
Pb-210+D	Scrap shredder	1.0e-02	2.8e+00	2.8e-09	7.6e-08
Ra-226+D	Scrap truck driver	1.4e-01	3.7e+01	1.0e-07	2.8e-06
Ra-228+D	Scrap truck driver	7.3e-02	2.0e+01	5.6e-08	1.5e-06
Ac-227+D	Scrap shredder	9.4e-01	2.5e+02	3.2e-08	8.5e-07
Th-228+D	Scrap truck driver	1.2e-01	3.1e+01	8.8e-08	2.4e-06
Th-229+D	Scrap shredder	1.7e-01	4.5e+01	3.3e-08	8.8e-07
Th-230	Scrap shredder	5.9e-02	1.6e+01	6.8e-09	1.8e-07
Th-232	Scrap shredder	6.1e-02	1.7e+01	1.1e-08	3.0e-07
Pa-231	Scrap shredder	1.9e-01	5.1e+01	9.6e-09	2.6e-07

^a Maximum risk—may correspond to a different scenario

Table 8-4. (continued)

Nuclide	Maximum Scenario	Dose		Lifetime Risk of Cancer ^a	
		mrem EDE per pCi/g	μSv per Bq/g	per pCi/g	per Bq/g
U-234	Scrap shredder	1.3e-02	3.4e+00	5.5e-09	1.5e-07
U-235+D	Scrap shredder	1.1e-02	3.1e+00	8.3e-09	2.2e-07
U-238+D	Scrap shredder	1.1e-02	2.9e+00	4.9e-09	1.3e-07
Np-237+D	Dross in landfill	6.5e-02	1.8e+01	4.7e-08	1.3e-06
Pu-238	Scrap shredder	6.3e-02	1.7e+01	1.1e-08	3.0e-07
Pu-239	Scrap shredder	6.9e-02	1.9e+01	1.1e-08	3.0e-07
Pu-240	Scrap shredder	6.9e-02	1.9e+01	1.1e-08	3.0e-07
Pu-241+D	Scrap shredder	1.2e-03	3.4e-01	1.2e-10	3.1e-09
Pu-242	Scrap shredder	6.4e-02	1.7e+01	1.1e-08	2.9e-07
Am-241	Scrap shredder	5.7e-02	1.5e+01	1.5e-08	4.2e-07
Cm-244	Scrap shredder	3.7e-02	9.9e+00	9.7e-09	2.6e-07
U-Natural	Scrap shredder	1.5e-01	4.1e+01	1.1e-07	2.9e-06
U-Separated	Scrap shredder	2.4e-02	6.4e+00	1.1e-08	2.9e-07
U-Depleted	Scrap shredder	1.2e-02	3.3e+00	5.5e-09	1.5e-07
Th-Series	Scrap truck driver	1.9e-01	5.1e+01	1.4e-07	3.9e-06

^a Maximum risk—may correspond to a different scenario

8.3.1 Shredder Operator

The operator of the scrap-shredding machine is the RME individual for Fe-55, the two nickel isotopes, Sr-90+D, Mo-93, Tc-99, Pm-147, Pb-210+D, all but two of the actinides, and the three combinations of uranium isotopes and their progenies. These nuclides deliver most of their dose via the internal exposure pathways. Since the shredder operator is exposed to high concentrations of contaminated dust in the ambient air, he would have the greatest potential exposures via this pathway.

8.3.2 Scrap Transport Worker

The driver of the truck transporting cleared scrap to the scrap processor is the RME individual for 14 of the radionuclides that are strong γ -emitters as well as for the thorium radioactive decay series. The large mass of metal at a relatively short distance results in the highest external exposures, which are the principal exposure pathways for this group of nuclides.

8.3.3 Disposal of Dross in an Industrial Landfill

Burial of the dross in a landfill leads to the highest exposures from C-14, I-129, and Np-237. These are long-lived isotopes of elements that have low K_d s and hence would reach the aquifer within the 1,000 year time frame of the assessment. All three nuclides partition to the dross and deliver their doses via the internal exposure pathways.

8.4 EVALUATION OF THE RESULTS

Many of the observations in Section 7.3 regarding the radiological assessment of steel scrap are applicable to the aluminum analysis. The relevant issues from the steel analysis, as well as questions that are unique to aluminum, are discussed in the following paragraphs.

8.4.1 Dilution of Potentially Contaminated Scrap

The assumption that all the aluminum scrap released from Paducah would be sent to a single facility is not unreasonable. The secondary smelter in question is relatively near Paducah; however, the intrinsic value of aluminum is such that transportation costs are not the determining factor in selecting a recycling facility.

8.4.2 Exposure Pathways

External Exposure

The comments about the external exposure calculations in Section 7.3.2 are applicable here and need not be repeated.

Inhalation

In the scrap shredder scenario, where the inhalation of dust and/or fumes is a major pathway, the aerosol concentration is based on an actual measured value. The assumption that all of the dust comes from the metal is reasonable for this scenario.

8.4.3 Airborne Effluent Releases

The evaluation of airborne effluent releases presented in SCA 1995, the basis for the assessment of the radionuclides listed in Table 8-3 (except C-14 and I-129) used much more conservative parameters than those used with CAP-88 in the present analysis. The earlier study assumed that all the food consumed by the RME individual was home-grown, that the radionuclide

concentrations in the soil reflected buildup over a ten-year period of continuous emissions, and that the individual resided between 100 m and 500 m from the facility, rather than the 1-km distance assumed in the present analysis. Additional differences are caused by the use of FGR 11 dose factors in the earlier analysis⁴. The calculated doses for this pathway are one to five orders of magnitude smaller than the maximum doses from the same radionuclides as listed in Table 8-4, with the exception of I-129, which employed the more realistic CAP-88 assessment⁵. Consequently, this scenario would not deliver the maximum dose from any of the nuclides listed in Table 8-3, regardless of which model were employed.

Ten nuclides were omitted from the airborne effluent release analyses. Six of these nuclides—Zn-65, Nb-94, Ag-110m+D, Sb-125+D, Ce-144+D, and Eu-152—are strong γ -emitters which deliver their doses primarily via external exposure, the RME individual being either the scrap truck driver or the taxi driver. The normalized doses to the scrap truck driver from Co-60 and Ru-106+D, two strong γ -emitters which were included, are four orders of magnitude greater than the corresponding doses from the airborne emissions pathway. Since the release fractions of these nuclides are similar to or greater than those of the six omitted γ -emitters, there is no reason to believe that the doses from this pathway would be significant for the latter six nuclides.

The four other omitted nuclides—Fe-55, Mo-93, Pm-147, and Cm-244—deliver their doses via internal exposure, the RME individual being the scrap shredder. Since the release fractions of these nuclides are equal to or smaller than those of other nuclides which also decay by α - or β -emission or by electron capture, there is again no reason to believe that the airborne release scenario would produce significant doses from these nuclides.

8.4.4 Ingrowth of Radioactive Progenies

As was noted in Section 6.3.4, there was no need to consider the ingrowth of radioactive progenies in the assessment of manufactured products made from cleared carbon steel scrap,

⁴ As discussed in Section 8.2.6, the atmospheric releases of C-14 and I-129 were assessed using the CAP-88 code and were corrected for the ICRP 68 DCFs.

⁵ One other exception is Th-228+D. The dose from atmospheric releases, calculated by the SCA 1995 model, is about one-fifth the maximum dose from this nuclide in the present analysis. However, if the atmospheric assessment were corrected for the ICRP 68 DCF for inhalation, the principal pathway for this nuclide in this scenario, the dose would be approximately one-tenth the maximum dose.

inasmuch as radionuclides which partitioned to the finished steel would not display significant ingrowth during the useful life of such products. This is not the case for aluminum recycling. As shown in Table 8-1, the partitioning of most contaminants is much less clear-cut than in the case of steel. Of the two manufactured product scenarios included in the aluminum analysis, only the taxi driver would receive doses which are comparable (i.e., within an order of magnitude) to the maximum dose from any radionuclide. (The doses from frying pan scenario are significantly smaller than the maximum dose from any radionuclide.) Since all of the dose in this scenario is through external exposure, only those γ -emitting progenies that would have significant ingrowth during the 7.3-year useful life of this product needed to be considered. The only such nuclides that needed to be addressed were Ra-228+D and Th-228+D, which form the Th-232 decay chain. The ingrowth of this progeny, modeled by means of the Bateman equations, was explicitly incorporated into the assessments of Th-232 and Ra-228+D in this scenario.

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